CPE 200: The small bear project

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Introduction

The primary goal of the small bear project was to both design and help run the animated stuffed animal elective class CPE 200 for the 2013 Winter Quarter at Cal Poly. The project started with a prototype built last year by Professor Hugh Smith and some insights from last time the class was run. The two main sections of the project were split by quarter, with the first quarter consisting of primarily testing and rapid prototyping a new cheaper design for the animated stuffed animal along with some rough course planning, immediately followed by the second quarter where time was spent primarily assisting students and making modifications on the project to help fix any problems that arose during implementation.

The first quarter spent prototyping had three main sections: design the power board, modify the frame, and prepare the lab and other logistics for the course to be run the following quarter. The power board construction consisted primarily of analysing last years prototype for the board and making some modifications to switch from battery power to a wall plug as well as testing some new testing expansions to help with debugging. The second main task was to create a frame using cheaper materials than last year while still mounting the servos in the correct positions for operation. The third and final part of the first quarter included ordering and organizing the parts for the class as well as some quick outlines of course schedule and setup of the primary lab for construction.

The second quarter was spent working as TA's and supporting the class throughout its course. The class was structured so that students were placed into groups of two and partnered with one other group and a TA who would walk them through construction and assist with any problems along the way. The TA's were trained during the first two weeks of the course and along with regular construction we were present at all of the lectures to assist with debugging and solve any problems that cropped up for the students. The final responsibility during the second quarter was holding open lab hours to help solve problems during the second half of the quarter.

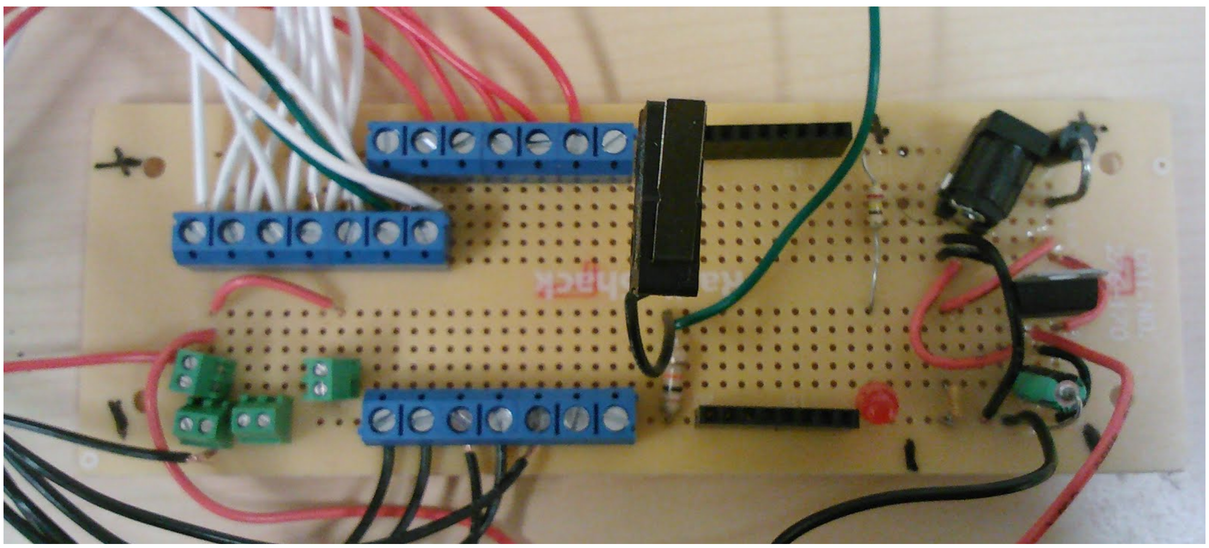
Power Board

A power board was created to power the 5 servos used by the bear because the Arduino board is unable to provide the necessary amperages for all the servos. The board takes in 9V from the wall wart and provides this voltage to the Arduino board and voltage regulator. The voltage regulator is a 6V regulator and feeds this voltage to the power rail. A rectifier diode drops the 6V down to roughly 5.4V.

The 5 servos are powered from the power rail and takes in roughly 5.4V. The voltage range for the servos are ~4-6V. The 5 wires are screwed down in the screw-down header. The screw-down header towards the bottom of the board is used for servo and sensor signal. The last screw-down header is used for ground. The green screw-down headers is used for the distance sensor. Two are powered by the Arduino which provides 5V, and the other two are used for ground.

The wires used for connecting the Arduino with the power board consisted of 3, 4, and 5 pin headers. This was done for both safety and convenience; the pins would connect more securely in the Arduino and there would be no floating pins while the board was live to prevent unlucky short circuits.

See Appendix for the Power Board Overview and Wire Information used in the course.



Bear Frame

The frame for the bear was constructed mainly out of circular PVC pipes and rectangular PVC pipes to mount the standard servos. The frame also makes use of L-shaped PVC trims to mount the micro-servos and metal struts to move the bear's limbs and head.

Standard servo mount:

1. Cut off a section of the rectangular PVC that is 3 ⅜ inches in length using the handsaw.
2. Slide the standard servo into your rectangular PVC.
3. Estimate the length of the round PVC for the left arm, right arm, and head. Cut the PVC pipe with the PVC cutters.
4. With the servo still inside the rectangular PVC, put the round PVC pipe inside through the other end and center it. Push the PVC pipe until it is roughly ½ inch away from the servo.
5. Mark two spots on the square PVC over the limb for drilling. The measurements should be approximately 1 inch apart.
6. Remove the large servo from the square pvc while keeping the round pvc inside
7. Using the drill press and the 9/64 drill bit, drill holes through the dots previously marked. Be sure to drill all the way through both the PVC pipe and the rectangular PVC.
8. Using the #8-32 machine screws, screw in through the newly drilled holes.
9. Place the standard servo on the top of the newly constructed limb, feeding the wires out of the side with the round pvc.
10. Screw in a #6-32 ⅜ screw into the servo top on the mounts that are halfway covered by the rectangular PVC.
11. Verify the servo is secure by giving it a small tug around its top.

Arm mount construction:

1. Cut off a 3 ⅛ inch section of the L-shaped PVC.
2. Decide which arm the piece is for. Insert Picture?
3. On the top of the limb, measure and mark 9/16 inch from the front of the arm for the large hole.
4. Mark ⅜ inch from the side on the top portion of the limb.
5. Translate the locations to the inside part of the arm to find the location of the large drill site.
6. From the bottom of the side, mark a line ⅜ inches up.
7. On the side, measure and mark ¼ inch and 1 ⅜ inch from the front.
8. Translate the side points to the inside of the arm for zip tie hole locations.
9. Using the drill press, drill a hole in the top using the ½ inch drill bit.
10. With the ⅛ inch drill bit, drill out a smaller section of the large hole towards the back of the arm. This allows the small servo to fully fit with its unusual shape on the top.
11. With the 9/64 inch drill bit, drill holes for the zip ties on the side of the arm.
12. Ensure that the small servo can fit the arm section securely through the top, if not, drill as necessary.
13. On the back section of the top, mark out a box 1 ⅜ inches in and ½ inch from the inside.

14. Using the bolt cutters, cut along the lines drawn.
15. Verify the arm has full range of motion on the theoretical arm mount. Cut a larger section off if necessary.
16. Mark and measure 7/16 inch and 13/16 inch from the back of the L-shaped PVC.
17. Using the 1/16 inch drill bit, drill through the marked locations.
18. Slide the micro-servo through the large hole.
19. Use a zip tie and tighten until the micro-servo is secure.
20. Verify the micro-servo is secure by giving it a slight pull.

Course structure

The class CPE 200 itself was set up to be run through three main parts consisting of power board construction, frame construction, and software development. The TA's were kept at least one week ahead of the students via weekend meetings covering necessary material. By training the TA's directly and being on call to answer questions, the class was able to run very smoothly with only small problems occurring throughout the first two parts of the course. The third part of the course ran into some trouble with students forgetting to tie their arduino and power board grounds together, as well as servo problems. The digital micro-servos we got for use in the arms of the bears ran into a large amount of trouble with multiple failures and a large amount of erratic twitching. The problem was mitigated by replacing them with analog servos but it did cause some delays in the course plan as well as creating some extra difficulty in program testing. The entire course structure is listed in the appendix.

Things to consider for the next iteration of the course.

Throughout the lifetime of this project there have been a number of notable things that went extremely well or would have been helpful and would assist with the next run of this course, the are listed below along with descriptions for easy analysis:

1.Lab organization: The lab, routinely used for the construction and modification of the bears over the course of the quarter, was unfortunately not as well maintained by the students as could be desired. The deterioration of the lab was managed by unofficial biweekly sweeps that consisted of cleaning up clipped wires and reorganizing things to improve accessibility along with structure of the lab. One of the main ideas for better lab management would be to have stricter rules on lab maintenance as well as getting a larger materials storage container with small containers for all the required parts. If all the parts are organized in a single location it will be easier to maintain things.

2.Heat sink for voltage regulator: The current board setup does not include a heatsink on the voltage regulator. During regular use, this is not a problem, but due to consistent errors and pinned servos during testing it looks like a heatsink would save time and effort repairing damaged power boards if they came standard with some form of heatsink to prevent overheating. There are standardized heatsinks for the voltage regulators and they should be used to assist in debugging by allowing more problems to occur before the board fails.

3. Open lab hours: During the second half of the course open lab hours were held from 5-8pm on multiple weeknights. Although they would not be very useful early in the quarter they proved to have extremely high attendance during the closing weeks and seemed to have a very positive effect in both the students understanding of the material as well as helping them catch up when they fell behind in the class. To run the open lab hours in the future there will still need to be some experienced TA’s are needed but having multiple dedicating time seems to help. To help gauge interest in the open lab hours they can be started around week five with one or two sessions a week but once the visiting number of students increase they can be increased to encompass most of the week near the end to accommodate the needs of the current students.

4.Extra tools in the lab room: The lab had at least one of every tool required by the project, but there were times where, due to there only being one of a specialty tool, groups had to wait while another team was working. The most prevalent case of this was the wire crimper, as a large number of wires needed to be made but only one group could be working on it at any given time due to a lack of a second crimper. The other tools that we had a shortage of wire strippers and cutters.

5. The grounding problem: One of the most prevalent problems in the class has been students either forgetting to synchronize the grounds between the power board or plugging it in improperly. The current power solution for the arduino is a three pin header that contains lines for a 9V line from the power board, a 5V line from the arduino for sensors, and finally a ground line to

create a common ground for the system. The main damage has come from students simply neglecting to connect the power wire during testing; this results in erratic servo movement and has damaged a number of the small servos. The secondary problem has been a reversal of the power connector, that is, the 9V and 5V line have been switched resulting in a fried arduino board. The only real solutions to this problem are either change the wire setup to require the grounds to be synched for servo use or spending more time in class emphasizing the importance of the common ground. Some different colored wires in the spec would help to reinforce the idea as the current system had half of the 5V line remaining red which may have caused some confusion. If no solution can be found to require the ground be added to the servo lines, a greater emphasis on common grounds will be needed to prevent the damage we have seen this quarter from occurring again.

Appendix:

CPE200 - Small Bear Class - Week by Week (Draft) Schedule
Winter 2013

Week 1:

Lecture: Syllabus, Overview of the bear (need Arduinio, PVC structure and power board, sensors), assign teams (need team worksheet), give out permission numbers

TA Coordination meetings:

- Tuesday 9 pm - Assign TAs to teams, give out CPE400 permission numbers, give overview of the class (they need to provide their own arduinos),
- Sunday (noon) - Lab overview and safety, building the power board, create the kits

TA/Student meeting

- Data sheet homework (due at the beginning of lecture week2)
- Upload Team picture to polylearn(due by the beginning of lecture week 2)

Week 2:

Lecture: Go over the power board (components and use for these), purchase the kits (label boxes by team number), Lottery for bears (give them out, label them by team number)

TA Coordination meeting:

- Sunday - Build the PVC structure

TA/Student meeting:

- Begin the building of the control board (go over soldering, build it, test it)

Week 3:

NO Lecture Week 3 (Holiday)

TA/Student meeting

- Finish building control board, test it
- Add wires to the sensors
- Develop use cases for their bears (when x happens, the bear does y), where will they mount their sensors (due at the beginning of lecture week 4)

Week 4:

Lecture: Introduction to programming the arduino, State machine

TA/Student meeting

- Overview of the PVC structure (will not really be covered in lecture - TA's will cover this)
- Students start pvc frame, mount large servos
- State machine homework (using switch on control board, LED on pin 13, create a state diagram that controls it) - assignment includes both creating the state diagram and then programming this for the arduino (due in two week)

Week 5:

Lecture: Overview of servos, continue state diagrams, (have in class lab to implement a simple servo control state diagram)

- Students turn in their use cases

TA/Student meeting

- Continue pvc frame,
- Create wires
- Finish State diagram/programming assignment (due at the beginning of lecture week 6)
- Start state diagram for the bear (due in 2 weeks)

Week 6:

Lecture: Overview of the distance sensor, Probably more on programming state diagrams

TA/Student meeting

- Finish PVC frame (if not done yet)
- **Create wires**

- Test out servos and find out max and min points (where each servo is quiet at the max and min settings)

- Finish state diagram for the bear (due at the beginning of lecture week 7)

Week 7:

Lecture: TDB

TA/Student meeting

- Continue to create wires?
- Begin to program the state diagram for the bear

Week 8:

Lecture: Programming

TA/Student meeting

- Software / catch up week in case of problems

Week 9:

Lecture: Programming

TA/Student meeting

- Software

Week 10:

Lecture: Show off the final product in lecture

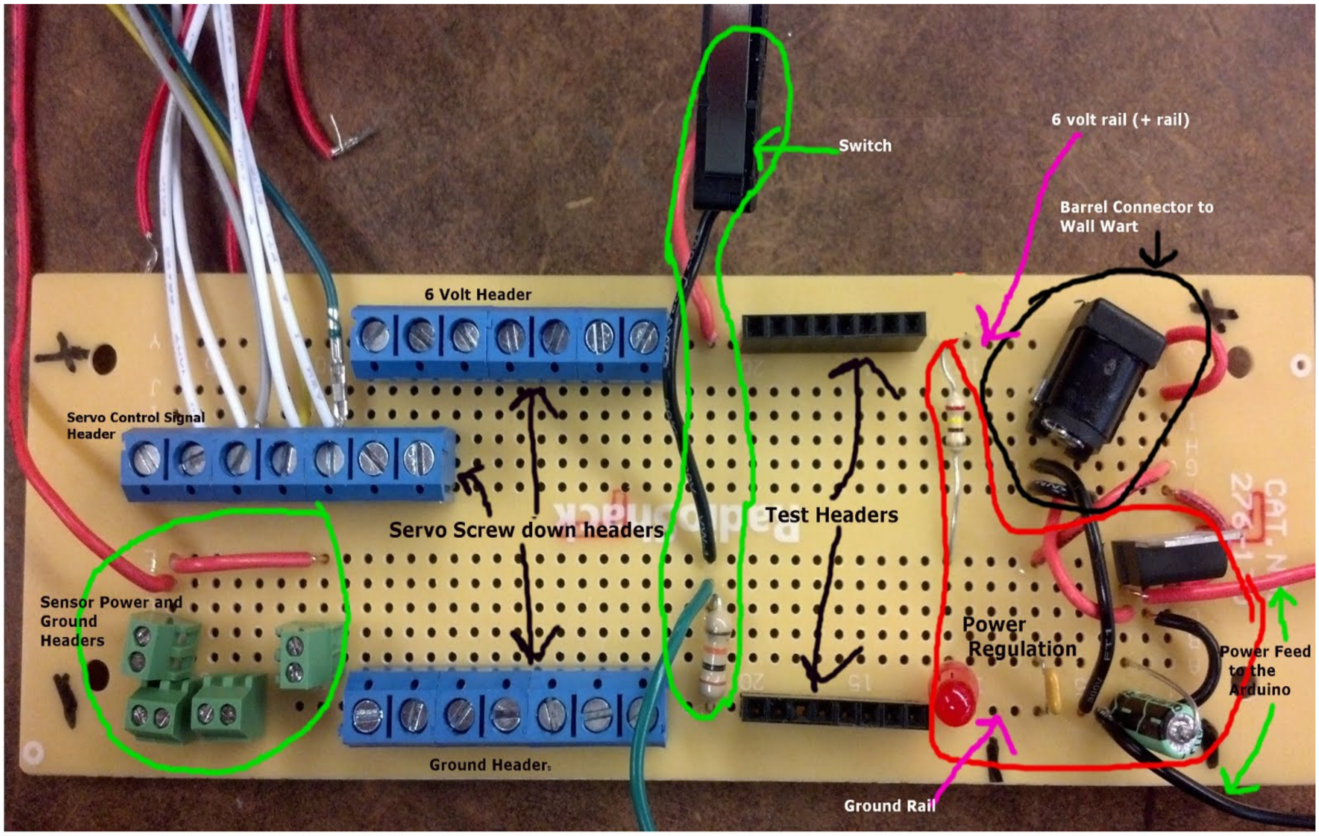
Power Board Overview

Why do we need this board?

- Arduino board cannot provide the current we need - we need ~250 milliamps per servo
- The servos work better with 6 volts, the arduino outputs 5 volts
- We need 5 volts for the sensors (which comes back from the arduino)
- The screw down headers make connecting things much easier

The power board has a number of functions. These include:

1. Provide the connection the the 9 volt wall wart (transformer)
2. Create (voltage regulator) and provide 6 volt and ground to the servos
3. Provide a location for the servo control lines to meet up the control lines from the arduino output pins.
4. Provide a wire for a common ground to connect with the arduino
5. Provide 5 volt and ground connections for the sensors
6. Provide a switch for testing



The power board (really a power distribution board) has six main structures:

1. **Power regulation** - the board accepts 9 volts from a wall wart (transformer) and converts this to 6 volts to be used by the servos. The output of this is sent to the two rails along the edge of the board (one rail for 6 volts and the other for ground)

   This consists of:

a. DC Barrel Jack - to connect the wall wart to the board
b. Voltage regulator - converts the incoming 9 volts to 6 volts
c. Two capacitors - required by the voltage regulator (see voltage regulator data sheet)
d. Red LED + resistor - this is connected to the 6 volt output of the voltage regulator to show that the board has power.

1. **Power feed to the arduino** - the arduino may be powered by the power control board. To do this you will wire it so that both the 9 volt input voltage from the wall wart and the

ground is available (via wires) to connect to the arduino's power in and ground connections.

This consists of:

a. One red wire (9 volt) - This wire should only be connected to the arduino if the ardunio is not being powered by its USB connection.
b. One black wire (ground) - This wire should always be connected to the arduino group. Everything (arduino, power control board, servos...) all need to have a common ground.
c. Note - When not using the red wire, you will need to put something over the end of the wire to make sure you do not short out your board.

3. **Switch for testing** - This switch connects between the 6 volt rail and ground and provides a signal that can be used as a digital input to the arduino. This is for testing only.

This consists of:

a. The switch - The switch is connected to the 6 volt rail using a short wire
b. A resistor - to limit the current flow when the switch is pressed
c. A white wire - to connect to a digital input on the arduino board with male connector.

4. **Servo power and testing headers** - these headers let you easily plug in a wire to power your servo. These are for testing only.

This consists of:

a. One four pin female header on the 6 volt power rail
b. One four pin female header on the ground rail

5. **Servo Power and Control screw down headers** - these are three headers (one for 6 volts, one for ground and one for control) to screw in the wires to be used to connect the power board to the servos

This consists of:

a. One 7 connector screw down header on the 6 volt rail
b. One 7 connector screw down header on the ground rail
c. One 7 connector screw down header towards one end of the board- This is used to connect between a wire from the arduino to control the servo and an output wire that goes to the servo.

6. **Sensor power headers** - These smaller headers are used to provide 5 volts and ground to the sensors.   (Note - the sensor output lines will be connected directly to the arduino.)

This consists of:

a. One red wire with a male end - this wire will be connected to the arduino’s 5v output header. (The arduino provides the voltage regulation from the 9 volts to the 5 volts - so we do not have to.)
b. Two small screw down headers - connected by a wire to provide 5 volts
c. Two small screen down headers on the ground rail to provide the ground for the sensors

Analysis of Senior Project Design

Summary: The primary deliverables for this project are the power board and bear frame designs, as well as partial credit for the CPE 200 course as its execution was the primary focus of the project. The power board plugs into the wall and provides both a 9V power supply as well as a 5.4V voltage rail for using in powering an animated stuffed animal. The frame is designed to allow for simple programming and animation providing five movable joints for students as well as a distance sensor and button for input to a state machine control system.

Primary Constraints: The main challenges of this project consisted of finding a cheaper solution to an already established system (the frame and power board construction), as well as the logistics side of things such as organizing and acquiring all the necessary components for the lab. The final challenge was dealing with unusual problems and difficulty in the actual course implementation, that is, solving all the unusual problems that crop up during the students implementation of our design.

Economic:
Original estimate cost of components: ~ $100 per bear was that target cost
Actual final cost of components: ~ $105 per bear due to servo failures and added diode
Additional equipment costs: The only other main costs would be from upkeeping the lab and the drill press used in the frame construction.
Original development time estimate: one quarter design and testing followed by the course.
Actual development time: one quarter with two weeks of winter break added for final course development to finish.
Environmental: The only environmental problem foreseen with this project comes from soldering and the scraps of PVC cut during the frame construction.
Manufacturability: The frame construction was primarily designed through rapid prototyping and testing different mechanical solutions directly with the tools in the lab. The servo mounting solutions generated were found to be far cheaper and easier than the previous setup due to a decreased reliance on the square PVC blocks by substituting standard PVC and using mounting screws to make connections.
Sustainability:
Issues for maintained use: The main problem that could come up stems from the instability of the servos. The smaller servos have had a large number of stability issues with erratic twitching becoming common in around 30% of the servos used.
Project impact of sustainable resources: The project uses a large number of electronic components on both the frame and the power board.
Upgrades for the design: The primary upgrades for this design would be to improve stability with better servos or further decrease costs by implementing more micro servos into the project in place of standard servos.
challenges with updating: The main challenges with updating are cost of the servos, non indicative test samples (small number of a type servos will not guarantee the rest work properly) and moving away from the simpler mounting with the square pvc to a new system. The changes

are very possible but will require some more testing to be made viable before full implementation.

Ethical: The only real ethical concern is avoiding scaring people with the final implementation, an extremely jerky stuffed animal could scare some children.

Health and safety: The main safety concerns arise during construction with students using some dangerous tools. The main tools to watch out for are the drill press, the soldering iron, and bolt cutters as they can do the most damage.

Development: No real new tools were learned but the project served as an excellent refresher on standard circuit debugging in a live project as some unusual problems required extensive testing to solve